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Modeling Wheat Emergence Using Temperature and Photoperiod Data

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Abstract: Seedling emergence require quantitative information concerning the interaction of seebed environment and preemergent seedling growth. The objective of this study was to predict the time of emergence of wheat by using mathematical models based on temperature and other indices. Wheat was planted at Malakandher Farm, Agricultural University Peshawar on six dates from 15th October to 30th December 1997 with 15 days interval. Days to emergence and rate of emergence and various indices were computed using the weather data. Coefficient of variation with low value was used as a criteria for predicting the seedling emergence. It was found that the product of mean temperature and photoperiod most accurately predict the seedling emergence of wheat compared with other indices as it has the lowest value among the six planting dates. Results show that this model is a useful tool for investigating the effect of temperature and other indices on seedling emergence.

Key words: Modeling, temperature, photoperiod, emergence, wheat

Introduction

Seed germination which is the protrusion of radicle from testa of the seed and development of the seedlings to a stage where all the essential structures indicate their ability to form a satisfactory crop under field condition (Bekendam, 1982). This germination is a complicated metabolic event influenced by a range of environmental factors including temperature(soil and air), matric potential and photoperiod (Weaich *et al.* 1996, and Collis-George, 1987). Among these environmental factors temperature is playing a major role in germination and there an optimum temperature limit for different species (Kevseroglu and Caliskan, 1995). Optimum temperature is the one at which maximum germination occur in the shortest possible time (Sagsoz, 1990). Generally optimum temperature are preferred for germination and plant growth. It will be useful to know about the maximum, minimum, and optimum temperature required for the growth and development (Kevseroglu, 1997).

Soil temperature is another factor affecting plant growth, development and germination particularly the rate of emergence. The rate of emergence which is the function of temperature, the diurnal variation in temperature, photoperiod is directly dependent on soil temperature.

For modeling growth and development of wheat, it is necessary to predict when the seedling will emerge and will become autotrophic. Several studies have been conducted in the field to examine seedling emergence of various crop. Sethi *et al.* (1985), Sethi and Aggarwal (1986) and Lindstrom *et al.* (1976) studied wheat, Weaich *et al.* (1996), Bhatti (1995) and Dwyer *et al.* (1990) studied corn, Kevseroglu *et al.* (2000) studied sunflower and soybean, Brar *et al.* (1992), and Prostko *et al.* (1998) studied sorghum, and Huidobro *et al.* (1982) studied pearl millet.

Gilmore and Rogers (1958) reported positive relationship of heat units, growing degree day, and thermal units with growth and development. Emergence rate depend upon temperature and heat units which can be used to predict emergence (Shah *et al.*, 1995).

Very little published data on weather based mathematical modelling for wheat emergence is available particularly in Peshawar where variation in temperature, photoperiod and seasonal temperature variations are more than other wheat growing areas. The objective of the present study was to examine the seedling emergence of wheat using weather parameters to predict accurately the seedling emergence.

Materials and Methods

An experiment was conducted at Malakandher Farm, NWFP Agricultural University to study response of wheat to planting dates. The experimental site is located at 34° N latitude, 71.3° E longitude and an altitude of 450 meter above sea level having a continental type of climate. Three varieties i.e. Inqilab- 91, Bakhtawar-92 and BNS were sown on six dates i.e. 15th October, 30th October, 15th November, 30th November, 15th December and 30th December 1997. The experiment was conducted according to Randomized Complete Block Design with split plot arrangement, replicated three times. Planting dates were allotted to main plots while varieties were maintained in subplots. A subplot size of 3x1.8m having six rows, 3m long, 30cm apart was used. Seed was sown in rows using a seed rate of 100 kg ha^{-1} on well prepared seed bed with a single row hand drill. A basic dose of 135-55-0 kg NPK ha^{-1} in the form of DAP and urea was applied. Uniform hand weeding and irrigation were done when needed.

Days to emergence data was recorded by counting the number of days from sowing until 80% of the plants emerged in each subplot. Days to emergence averaged over three wheat varieties were calculated from the data recorded on three replications. Since there were no significant differences in replications of each planting date, data from all replications was averaged. Days to emergence was considered as the emergence time. Rate of emergence was calculated as the reciprocal of days to emergence. Daily meteorological observations were recorded at weather station located at the experimental site and were used to calculate various heat indices.

The following data for each day of the months of October 1997 to January 1998 was used in this study. Days of the months were considered as days of the wheat growing season, 1997-98 starting from October 10 as day 1 of the season and continued till January 1998.

Temperature maximum (Tx) in °C
Temperature minimum (Tn) in °C
Temperature soil (Ts) in °C
Wheat Growing Degree days (WGDD) in °C

Photoperiod (PP) was calculated according to Charles-Edwards (1982) using following formula:

$$h = 4.36 \times 10^4 + h_D \sin[2 (t + Z)/365]$$

where h is the seasonal variation in daylength, h_D is the seasonal amplitude of the variation in daylength, Z is the number of days the autumn equinox follow January 1st and t is the time variable

The following calculations were done using the weather data for each day of wheat growing season using Lotus 123 program:

Temperature average (Ta) = (Tx+Tn)/2 in °C

Growing degree days for winter season crops (GDDC) with a base temperature of 4.4 °C [(Tx + Tn/2] -Tb in °C.
where Tb = 4.4°C, the negative values were considered as 0 GDD for the day.
Nyctoperiod or night length = (NP) = 24 - PP in °C. hour

Tx . PP in °C. hour	Tn . PP in °C. hour
Ts . PP in °C. hour	Ta . PP in °C. hour
Ta . PP. PP in °C. hour^2	Ta . Ta. PP. in (°C)^2. hour
Tx . Tn. in (°C)^2	Tn > 3 in °C
Tx + Tn > 3 in °C	Tx . Tx > 3 in °C
Tx . Tx in (°C)^2	2Tx + Tn in °C

(Tx . PP)(Tn . NP) in (°C)^2 . hour^2

For the six planting dates cumulative values for days to emergence were calculated using the following formula:
CXi (dp-de) = $^e\Sigma$j-p (Xij)

where C stands for cumulative value
X = any weather parameter individually, or combination of the parameters
Σ = summation , i = planting date starting from date one to date six. j = any day of the emergence period from planting to
emergence, dp = planting day, de = emergence day
Mean (M), variance (Var), standard deviation (SD) and coefficients of variation (CV) were calculated for the six planting dates.

M = ΣX/n
Var = [Σ^2X - (ΣX^2)/n]/(n-1)
SD = square root of variance
CV = (SD/Mean) x 100

In order to predict emergence more accurately, the coefficient of variation was used as criteria for selecting the mathematical model, the one with low CV was considered to predict emergence with more precision.

Results and Discussion

Data regarding days to emergence is presented in Table 1. Wheat planted on 15th October took 8.44 days to emergence. Days to emergence increased with delay in sowing and crop planted on 30th December took maximum days to emergence (19.2). A significant linear relationship was observed when days to emergence was regressed on planting dates. October 15 was considered as first planting day of the season. Thereafter, planting on any other day was considered as late planting. Days to seedling emergence was increased by 0.139 day with each 1 day delay in planting from 15th October to 30th December (Fig. 1). This delay in emergence for late planting dates may be due to decrease in air and soil temperature during crop growing season (Fig. 2) and mean temperature on that particular date (Fig. 3). Germination of seed starts with imbibition of water and metabolism of the stored food within the seed. This process of imbibition of water and metabolism of stored food is temperature dependent

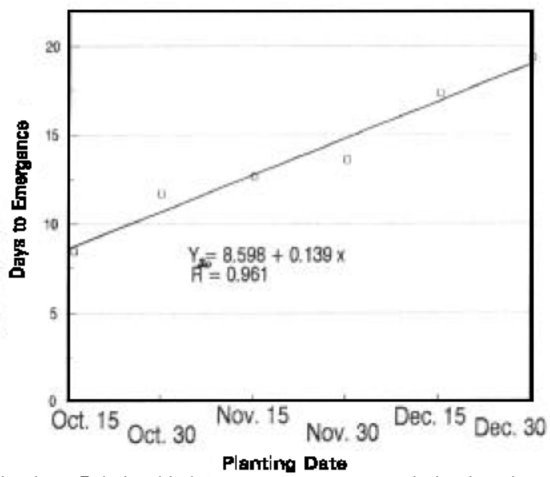

Fig. 1: Relationship between emergence and planting dates of wheat

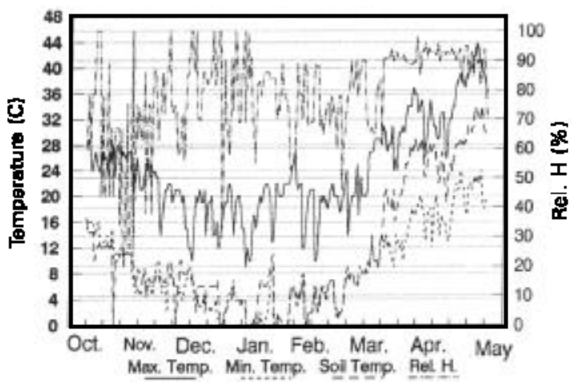

Fig. 2: Daily maximum, minimum, soil temperature and relative humidity during growing season 1997-79

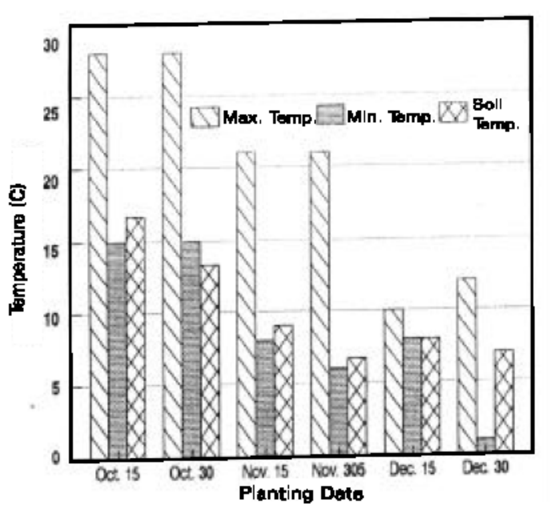

Fig. 3: Mean maximum, minimum and soil daily temperature recorded during wheat growing season (1997-98)

Table 1: Emergence date, day of growing season, days to seedling emergence and emergence rate of wheat planted on different dates.

Planting date	Days of season at planting time	Emergence date	Days to emergence	Emergence rate
Oct. 15	5	Oct. 23	8	0.125
Oct. 30	20	Nov. 11	12	0.083
Nov. 15	25	Nov. 28	13	0.077
Nov. 30	41	Dec. 14	14	0.071
Dec. 15	56	Jan. 1	17	0.059
Dec. 30	71	Jan. 18	19	0.053

Oct. 10 is considered as the first day of the planting season.

Table 2: Mean photoperiod duration, mean maximum, mean minimum and soil temperature of the six planting dates.

Planting date	Days to emergence	Temperature (°C)		Soil	Photo period	Nycoto period
		Maximum	Minimum			
Oct. 15	8	29.1	16.9	15.2	11.13	12.87
Oct. 30	12	26.6	11.2	10.3	11.66	12.34
Nov. 15	13	23.3	7.9	6.3	10.25	13.75
Nov. 30	14	20.0	6.7	6.8	10.04	13.96
Dec. 15	17	17.8	3.4	4.7	9.98	14.02
Dec. 30	19	16.8	2.8	0.5	10.08	13.92

Table 3: Cumulative heat indices, photoperiod and combinations of the parameters for the emergence periods of planting dates

	Planting date						Mean	Var	SD	CV
	D1	D2	D3	D4	D5	D6				
Days	8	12	13	14	17	19.0	13.8	12.5	3.5	25.5
CTmax	233	319	303	280	303	319.0	292.0	886.8	29.8	10.2
CTmin	135	134	102	94	57	54.0	96.0	1048.3	32.4	33.7
CTsoil	122	123	82	95	80	10.0	85.0	1427.2	37.8	44.3
CPhoto-p	100	128	143	151	180	202.0	150.5	1094.2	33.1	22.0
CNycto-p	116	160	193	209	252	278.0	201.5	2945.8	54.3	26.9
CTav	184	226	202	187	180	186.0	194.4	254.8	16.0	8.2
CGDD	184	226	202	187	180	186.0	194.0	254.8	16.0	8.21
CSGDD	122	123	82	95	73	7.0	83.6	1521.8	39.0	46.6
CPP*Tx	2594	3393	3108	2813	3023	3213.0	3024.0	68062.0	260.9	8.6
CNP*TN	1737	1791	1402	1312	799	752.0	1299.0	165633.0	407.0	31.3
CTs*PP	1565	1649	1132	1322	1122	140.0	1155.0	245290.0	495.3	42.9
CTa*PP	2368	3027	2783	2610	2524	2597.0	2651.0	43277.0	208.0	7.8
CTa*PP*PP	3047	4045	3824	3642	3539	3617.0	3619.0	930347.0	305.0	8.4
CTa*Ta*PP	4853	5732	4069	3290	2606	2606.0	3859.0	1333885.0	1154.0	29.9
CTx*Tn	3496	3569	2184	1702	953	930.0	2139.0	1157936.0	1076.0	50.3
CTn>Y1	135	134	102	92	32	45.0	90.0	1583.0	39.8	44.2
CTx*Tn>Y1	3496	3569	2184	1658	520	785.0	2035.0	1418288.0	1191.0	58.5
CTx*Tx	6061	8501	6707	5392	5299	5395.0	6225.0	1279942.0	1131.0	18.2
CTx*Tx+Tn	9096	9527	4790	3203	1671	1670.0	4993.0	1045358.0	3233.0	64.7
CTm=Tn+ .4(Tx-Tn)	174	208	182	168	155	160.0	175.0	299.0	17.3	9.9

SD = Standard deviation
CV = Coefficient of variation
CTmax = Cumulative daily maximum temperature
CTmin = Cumulative daily minimum temperature
CTsoil = Cumulative daily soil temperature recorded at 15 cm depth at 8:00 A.M.
CPhoto-P = Cumulative daily photoperiod
CNycot-P = Cumulative daily night period
CTav = Cumulative daily average temperature
CTmax = Temperature maximum
CGDD = Crop growing degree day

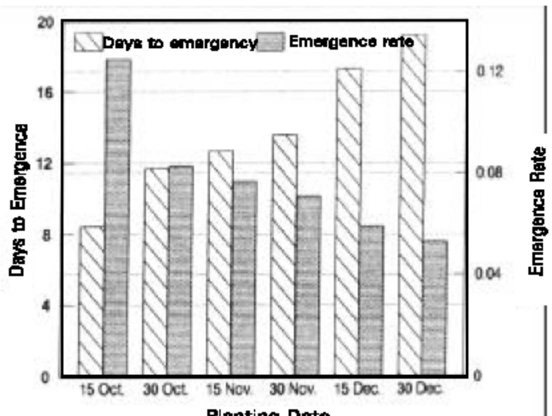

Fig. 4: Days to emergence and rate of emergence of wheat planted on different dates

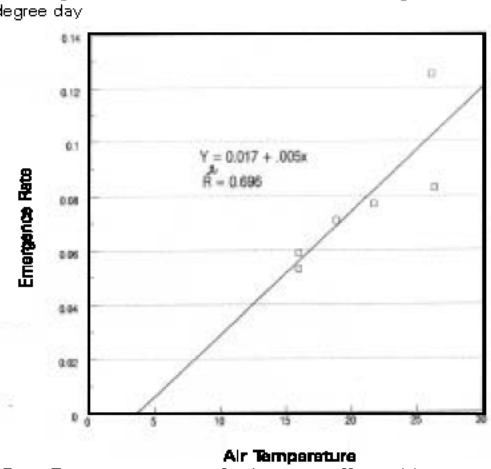

Fig. 5: Emergence rate of wheat as affected by mean air temperature planted on different dates

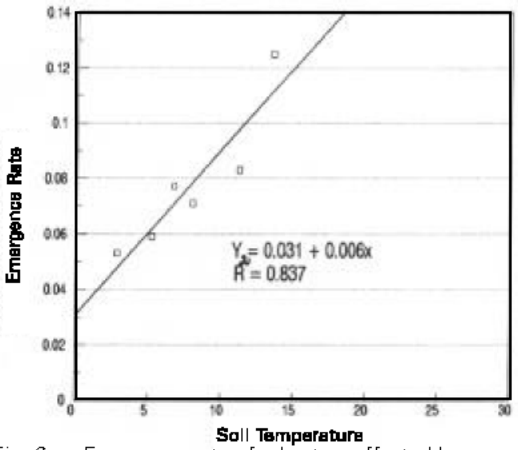

Fig. 6: Emergence rate of wheat as affected by mean soil temperature planted on different dates

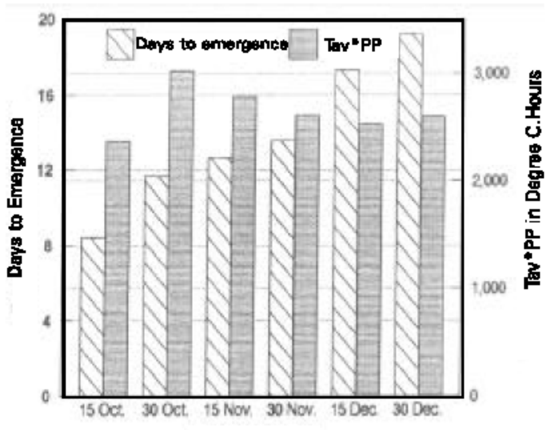

Fig. 7: Days to emergence and Tav* PP of wheat planted on different dates

and slows down as the temperature decreases. Wheat planted later required more days to complete imbibition and metabolism of reserved food due to low temperature and thus took more days to emergence than early planted crop. These results agree with the findings of Shah (1995), Kevseroglu *et al.* (2000) who reported delay in emergence with decrease in temperature. Mean maximum, minimum, soil temperature and photoperiod decreased with delay in planting from 15th October to 30th December (Table 2). However, mean nyctoperiod increased with delay in planting. Rate of emergence decreased with delay in planting from 15th October to 30th December (Fig 4). A significant linear trend was observed when the emergence rate was regressed on mean maximum air temperature and mean soil temperature (Fig. 5 and Fig. 6).

Different temperature indices including temperature, photoperiod and nyctoperiod are presented in Table 2. The coefficient of variation used as a criterion for judging the accuracy of parameters for predicting the emergence of wheat is given in the last column. The coefficient of variation showed that the product of mean temperature and photoperiod totaled for emergence period is most appropriate for predicting days to emergence of wheat (Fig. 7). Cumulative mean temperature, cumulative values of the product of temperature mean and photoperiod squared, nyctoperiod, cumulative value of the temperature maximum and temperature minimum above 3 °C. These indices are much better than wheat growing degree days (WGDD) and growing degree day for cool season crops (GDDC). Based on the results of this study, we have the basis for a mechanistic tool to investigate the effect of temperature and other indices on emergence. This study enabled us to identify which factor limit emergence under different temperature and other indices manipulated through various planting dates. This kind of modelling used for predicting emergence could be used for adjusting a proper time of planting according to different regions more productively.

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